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By

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Introduction

All of the information on the organism's reaction to weightlessness has come from observations of men and animals riding in rockets and aircraft following some form of Keplerian or ballistics trajectory (Ballinger, 1952; Von Beckh, 1954; Gerathewohl and Stallings, 1957; Gerathewohl *et al.*, 1957; Henry *et al.*, 1952). Although the continued development of high-altitude vehicles will certainly allow this method of direct observation to be increasingly useful, its current application is limited by the difficulty of maintaining accurate gravity-free trials for more than 30 sec.

Perhaps in response to the limitations of the method of naturalistic observation described above, several writers have outlined methods of simulating gravity-free conditions in ground-based laboratories. Campbell (1951) has suggested submerging subjects so that the "buoyancy of water counteracts the effect of gravity" (p. 69). Haber and Haber (1950) discuss the possibility of putting subjects into free fall by dropping them from high altitude balloons or down elevator shafts. Finally, Muller (1958) points out that the subjective aspects of weightlessness may be approximated by putting subjects in a liquid-filled cylinder and rotating them about their longitudinal axis in the horizontal plane. Although published results on the experimental use of these techniques are limited to one exploratory report by Knight (1958), who observed three subjects submerged in a water tank, this approach appears quite promising.

The work to be described in this report is based upon a different approach to the problem. Instead of attempting the direct observation or duplication of the gravity-free state in all its complexities, a single item was isolated to work with in the laboratory. This single factor is the *lack of bearing contact.*

Schema. If the physiological and subjective aspects of weightlessness

*The work reported in this paper was carried out as part of a larger program of research using turntables to investigate behavioral and perceptual problems in weightlessness. The larger program was carried out in association with Harwood J. Rhodes, Bucknell University, Lewisburg, Pa., and Octave Levenspiel, Illinois Institute of Technology, Chicago, Ill. The full program was supported by the United States Air Force (WADC) under Contract 33(616) 5418.

†Now on leave of absence as Special Research Fellow of the National Institute of Mental Health in the Department of Physiology, The University of Rochester Medical Center, Rochester, N. Y.

(Haber and Gerathewohl, 1951) are disregarded, the gravity-free state can be described as one in which man is in a field free of surface forces (Haber, 1952). Thus there is the complete absence of bearing contact between all body surfaces and external environmental masses. This condition will also obtain in a system when there is compensation for existing forces, as in the case of an untethered passenger in an orbiting satellite or a parachutist in free fall from a high altitude balloon.*

It can be shown by mechanical analysis that a person unsupported in space can turn in a desired direction or, if spinning slowly enough about an axis of the body, transfer the spin to another body axis and control the angular rate. Since the lack of bearing contact makes him a detached dynamic system, there is no way he can pick up or release angular momentum. By proper motions of his extremities, however, he can change body attitude. Assuming that he had no initial angular motion about any body axis, he would be able to induce rotation by arm and leg motions. After finishing the motions, he would again be stationary. However, assuming that he did possess initial spin about one body axis, he could arrest this motion by cycling movements of the legs, or he might induce rotation about another axis by proper phasing in of arm motions while altering the leg motions. Were he to stop all motions, he would again be spinning about the former axis in space, although now not necessarily the same axis of his body. The return to the initial state of motion in both cases (initial condition, stationary *or* moving) follows from the law of conservation of angular momentum.

The above description depicts a complex case in which bearing contact is absent on all body surfaces. The main ingredients can be applied to a simpler situation amenable to laboratory control in the following manner. By supporting a subject through a given body axis, friction or thrust effects for rotation about that axis may be effectively removed. The necessary conditions are that the support must have negligible friction, and that the axis of support must pass through the body axis for all motions to be studied.

Thus if a free-rotating frictionless turntable were used as support, a subject centered on it could be considered as having no bearing contact in the horizontal plane around the axis of rotation. As in the more complex gravity-free situation, the subject and turntable platform can be considered a detached dynamic system, with no transmittal of force between itself and surrounding objects.

If a man stands centered on such a turntable and swings his right arm to the right, his body will turn to the left (Newton's third law); if he moves his arm back through the same trajectory, he will end up where he

*In the latter instance this would occur prior to the point at which aerodynamic forces come into play. Starting from 100,000 feet, this would take about 15 sec.

started. However, if the subject is to change body attitude by rotary motion, he must move his arms to give him a mechanical advantage so that the body reaction to the arm return is less than its reaction to the initial swing. This shift in body position can be accomplished quite simply. Let the subject raise one arm to the front at shoulder height and move it in the horizontal plane through a 90° arc to the right. The amount of body rotation (reaction) is a direct function of the moment of inertia of the hand-arm mass. If he now drops his arm to the side and then moves it back to the frontal position in a small arc close to the body, the return body movement will be much smaller due to the decrease in the moment of inertia of the hand-arm mass.*

The discrete arm movements described above are quite adequate to control rotation on the turntable (they should also work in free space). A more efficient method is to smooth these motions into rapid rotary swimming movements in the horizontal plane. Counterclockwise motions initiate rotation to the right, or will stop slow initial rotation to the left. If the subject succeeds in stopping a turntable initially in motion and then stops the arm motions, the turntable will resume its rotation.

It will be apparent from the above discussion that the untethered subject in free space and the earthbound subject on a turntable have much in common. Although the body reactions to arm movements are simplified in the latter case due to the fact that the subject and turntable are anchored in a 1-g field, the physical principles and the general solution applicable to the problem are exactly the same. Thus, although a completely frictionless turntable is unobtainable, a low-friction turntable could provide a useful tool for the investigation of human performance in the absence of bearing contact.

Problem. Such a turntable was designed and constructed for use in the experiments to be described below. This investigation was designed to answer the following questions about performance in the absence of bearing contact:

(1) What is the initial rate and mode of adaptation for naive subjects attempting to perform simple tasks on the turntable?

(2) Does a rational or intuitive grasp of the physical laws applicable to the solution of problems presented the subjects accompany successful performance in these tasks?

(3) Will previous formal training in physics or relevant athletic experience show spontaneous positive transfer to the performance and/or understanding of these tasks?

*The distance the body moves in reacting to the arm swing will be a function of the torque applied (Newton's second law). Since torque (L) is defined as the moment of inertia (I) times angular acceleration (α), and moment of inertia is defined as mass times the square of the radius of gyration (mr^2), it may be seen that dropping the arm and narrowing the radius to the axis of rotation will decrease I, L, and the distance the body moves.

Methods

Design considerations. The selection of a turntable system was guided by the following criteria:

(1) It had to be stable enough to hold a 250-lb. man and allow him to move his center of gravity at head level 6 inches from the axis of rotation without exceeding the overturning moment of the turntable bearing system.

(2) Any wobble or tip occurring during rotation had to be below the threshold of perception for the subject.

(3) The turntable's coefficient of friction had to be low enough to allow it to start at 6 rpm and continue to coast through a 30-sec. trial regardless of the subject's hand or body motions.

Several bearing types were considered in the design of the apparatus.* The first choice had to be between mechanical and fluid bearing systems. Mechanical bearings had the advantage of low cost, design simplicity, and portability. Unfortunately, however, mechanical bearing friction depends upon load, and is largely unaffected by speed, producing constant deceleration. In contrast, fluid bearings are curvilinearly related to speed, with extremely good-performance characteristics at low speeds. In addition, the resisting torque of the fluid bearing at rest is theoretically zero; thus only the moment of inertia of the turntable and subject have to be overcome to initiate movement.

Among fluid bearings, the gas system (for example, air) has the lowest coefficient of friction. Unfortunately, these bearings are quite expensive, and the gas compressibility leads to design difficulties and the problem of instability. Thus the liquid type of fluid bearing was selected as the most satisfactory compromise. Both oil and water lubricated systems were considered. The water system was rejected due to the necessity of expensive rust-resistant material and of having a large pump to meet the flow requirements (computed to be 18 gpm to meet the design criteria). Thus the final choice was an oil-lubricated, liquid-bearing system.

FIGURE 1 contains a schematic diagram of the turntable and the hydrostatic (externally pressurized) oil bearing system which supported it. FIGURES 2*a* and *b* show a modified version of the main manufacturing drawing. The aluminum platform (2 feet in diameter) was attached to a vertical steel shaft. A pair of foot clamps held the subjects in place during the trials. This whole unit was supported by a film of oil (SAE 10, 250 psi, 5 gpm, 0.003 inch thick) formed at 1 thrust bearing used for vertical

*The design problems were informally discussed with Beno Sternlicht, G. E. Bearing and Lubricant Center, Schenectady, N. Y.; and Richard Elwell, of the same organization, initiated and carried through the final design on his own time. Rough machining, assembly, and maintenance were carried out by Lovell and Strouble Co., Williamsport, Pa., and the fine machining (± 0.0001-inch flatness per linear foot) was performed by the Lycoming Division of the Avco Mfg. Corp., Williamsport, Pa.

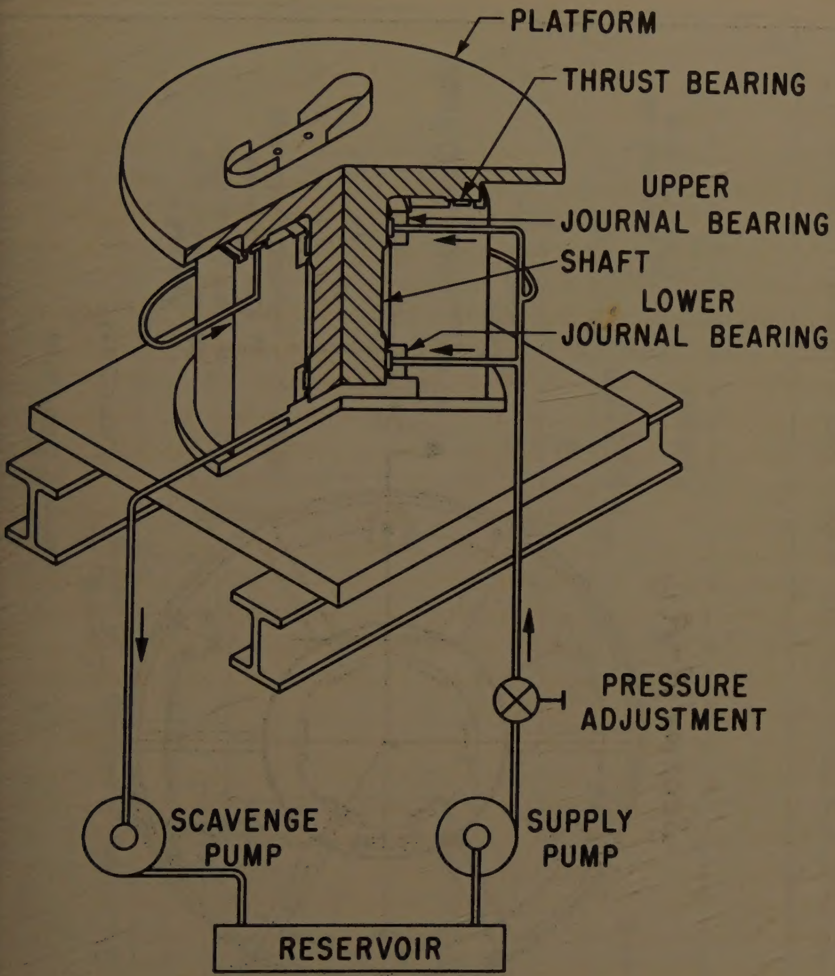
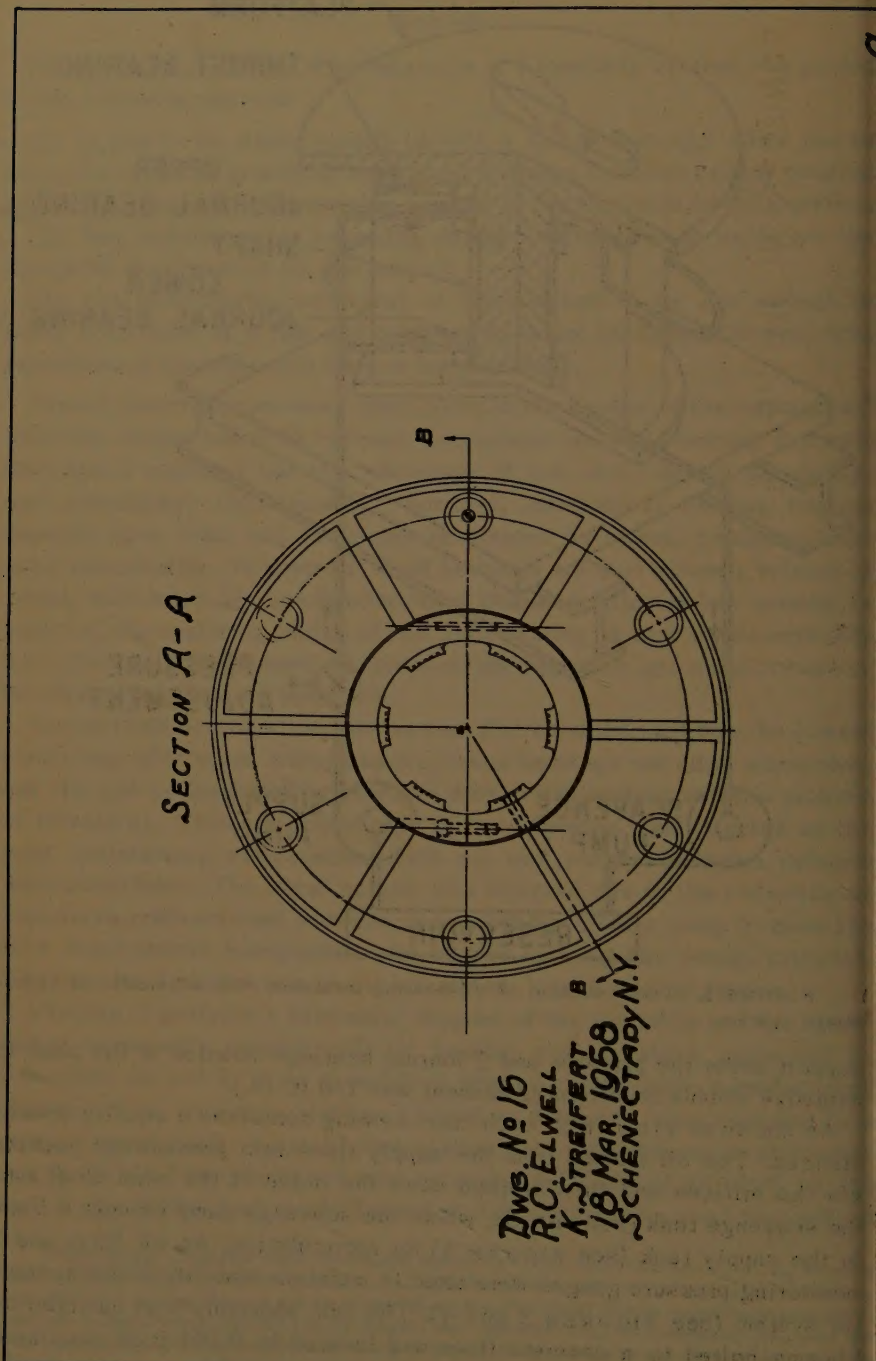


FIGURE 1. Cross section of oil-bearing turntable with schematic of hydrostatic system.

support under the platform and 2 journal bearings mounted at the shaft to minimize wobble (overturning moment was 150 ft. lb.).

As shown in FIGURE 2, each main bearing contained 6 equally spaced orifices. The oil flowed from the supply lines into pressurized pockets via the orifices and then drained down the sides of the main shaft into the scavenge tank (FIGURE 5), where the scavenge pump brought it back to the supply tank (see FIGURE 4) for recirculation. An oil filter and 2 monitoring pressure gauges were used to maintain stability in the hydraulic system (see FIGURES 3 and 4). The full assembly was mounted on I beams bolted to a concrete floor and leveled to 0.001 inch per linear foot.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B
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R.C. Elwell
K. Streifert
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Schenectady N.Y.

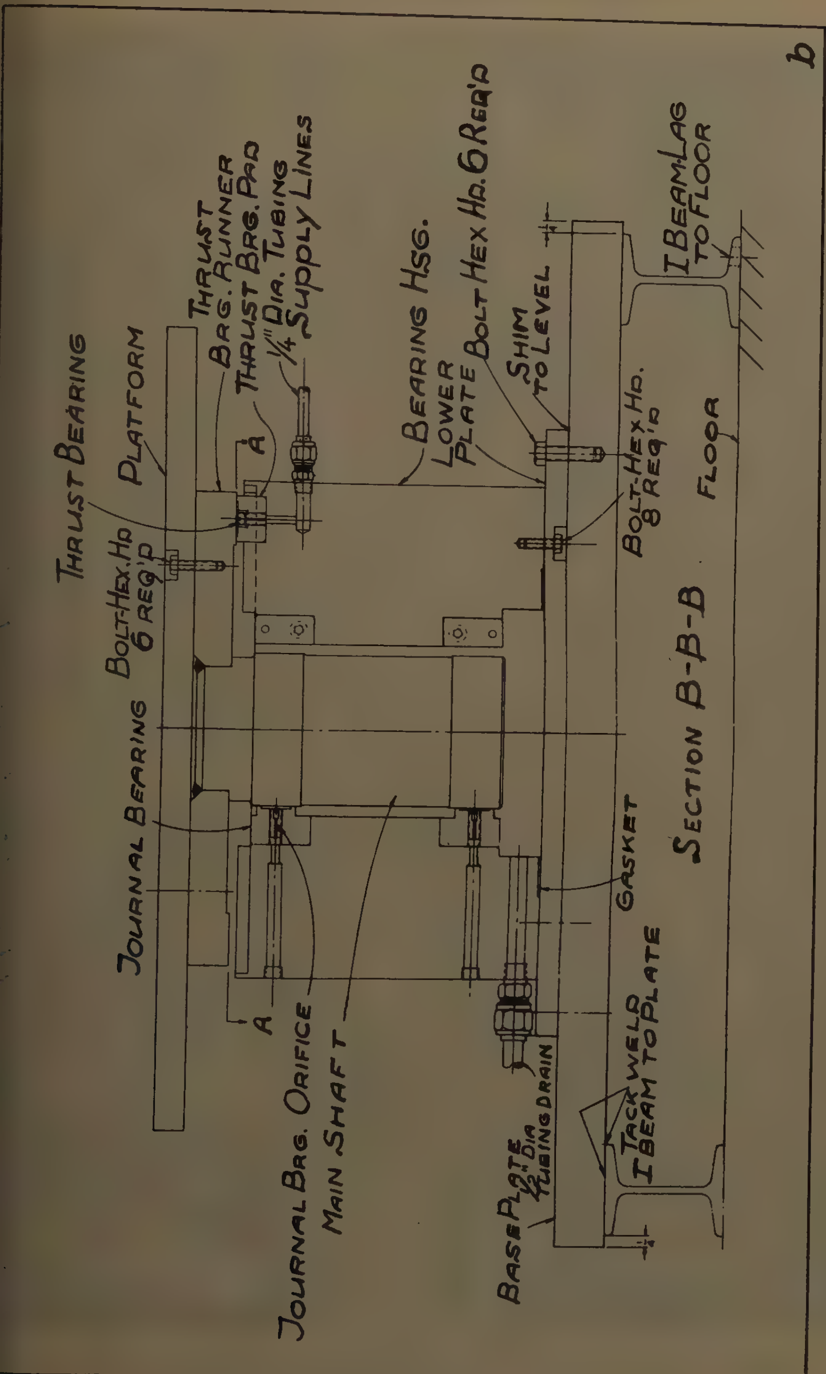

FIGURE 2. Copy of main working drawing showing general construction characteristics of oil-bearing turntables. (a) Top view. (b) Side view.

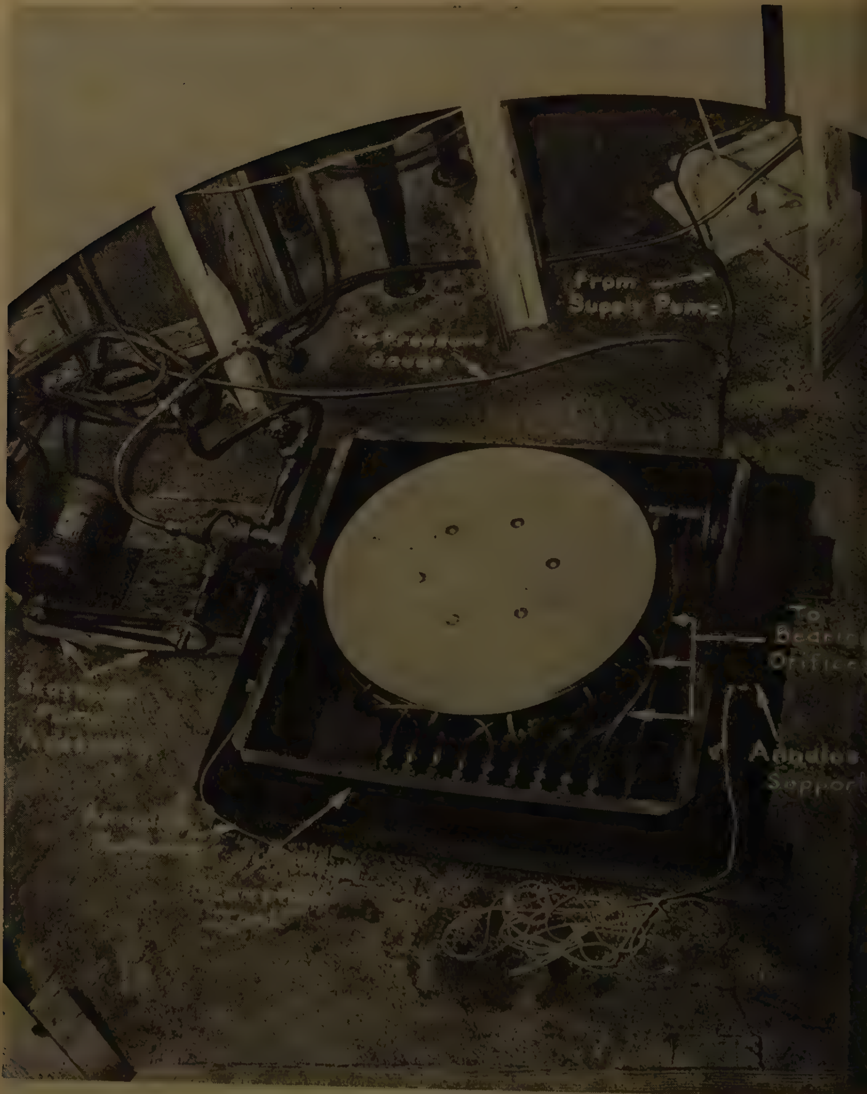

FIGURE 5. Interior of the enclosure as viewed through an open segment. The cover of the scavenge tank has been removed to show individual supply lines to the turntable.

FIGURES 3 through 7 show the characteristics of the turntable system as it was assembled for use in the laboratory. A hand-operated, spring-released friction drive (FIGURE 6) was used to initiate rotation for tests in which subjects were required to arrest platform motion. Steel screws were inserted beneath the aluminum platform at 60° intervals. These

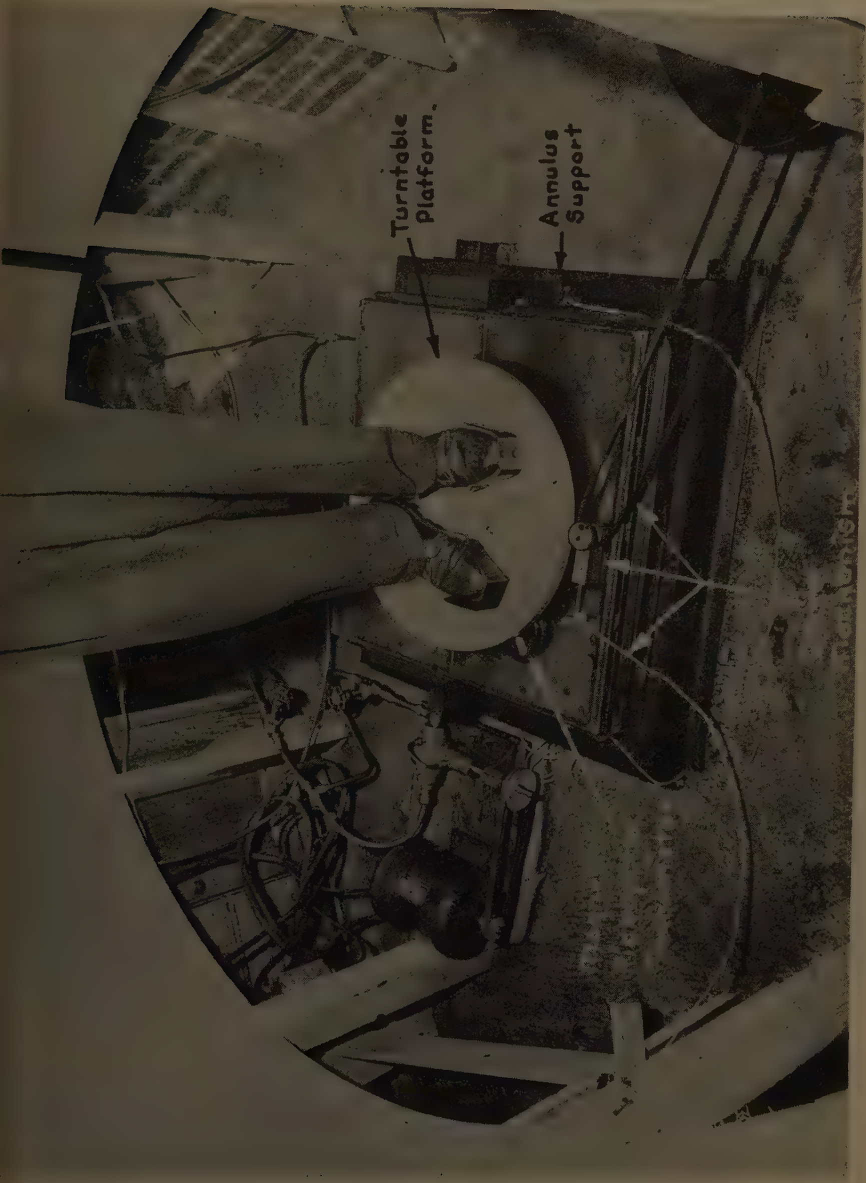

FIGURE 6. View of turntable with scavenge tank cover in place, showing subject standing on aluminum platform. Drive mechanism is used to bring the turntable to a selected rate of speed before it is released for tests of the subject's ability to arrest his free rotation.

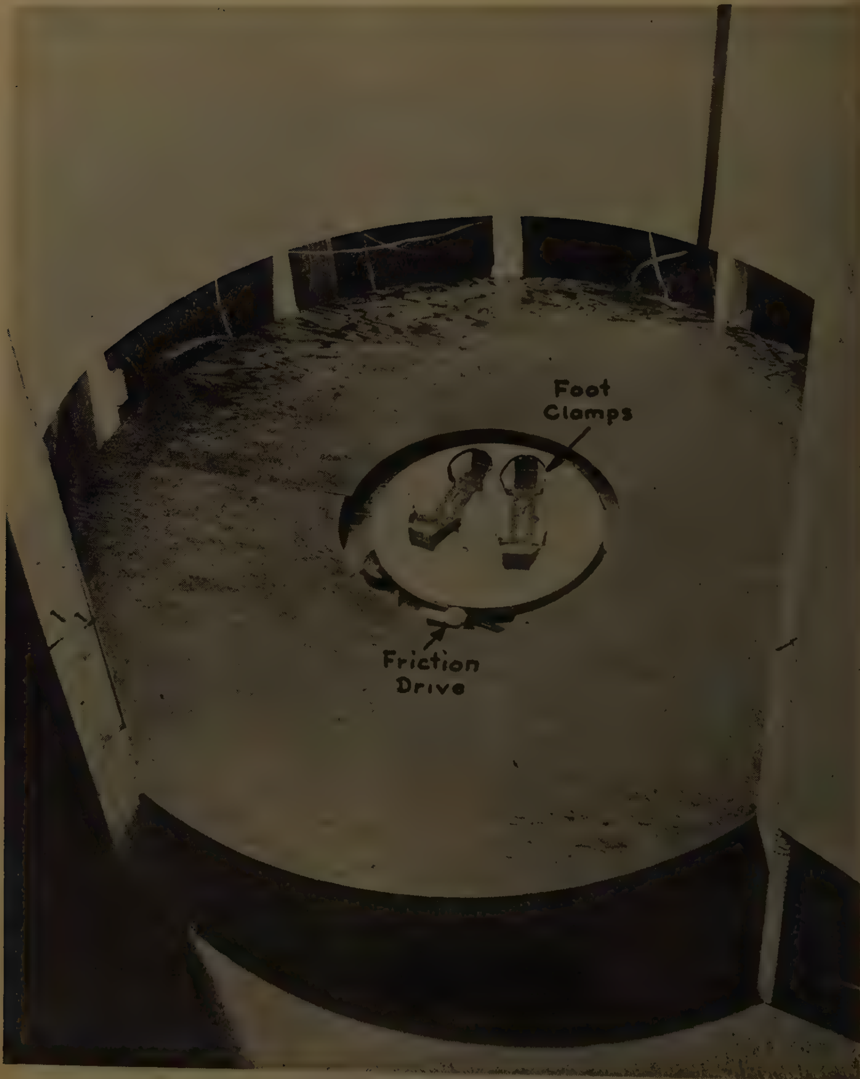

FIGURE 7. View of turntable with removable floor in place, showing clamps used to prevent the subject from shifting his feet during trials.

served as input to a magnetic pickup and amplifier* leading to a rectilinear ink kymograph that recorded rate of rotation within specified segments of arc.†

*Electro Products Corp.

†This tachometer system did not provide data reliable enough for quantitative analysis. Therefore, total time per trial was measured with a hand stopwatch.

The experimenter stood on a platform at the top of the experimental chamber, which consisted of a masonite enclosure 6 feet in diameter and 10 feet high (FIGURE 3). The subject entered through a movable quadrant of the wall. The floor of the room was painted black and its wall flat white. FIGURE 8 shows a subject mounted on the turntable in starting position awaiting the beginning of a trial.

Experimental groups. All subjects were male junior or senior college students. None had a history of any type of gross muscular incoordination. Three groups were selected on the basis of differences in past

FIGURE 8. Subject on turntable facing starting line and awaiting signal to begin test of his ability to make a 360° turn.

experience considered relevant to performance in the absence of bearing contact.*

Liberal Arts Students ($N = 22$). These subjects were classified as naive in relation to the requirements of the tasks to be performed on the turntable. None had taken courses in physics at the high-school or college level.

It was assumed these students were accustomed to moving about (as are all humans) by pushing against their surroundings (foot against floor and arm-and-leg surfaces against water in swimming); that is, with the normal use of bearing contact. Although all of them had probably had minimum contact with free fall, these experiences would have been so brief as to be almost completely dominated by factors active during thrusting off or loss of support.

Swimmers ($N = 15$). These men were chosen to match the liberal arts students as closely as possible in the lack of formal training in physics. All were members of the college swimming team and thus had more experience with the type of arm and leg control of body movements generally applicable to the no-bearing contact situation than either of the other two groups. This experience would have been gained in any formal or informal diving practice.

Engineering students ($N = 16$). This group was composed of engineering students selected on the basis of the successful completion of one year of college physics, plus advanced courses in statics and dynamics. Thus these students were trained in the principles of mechanics as applied to engineering problems and were familiar with Newton's laws of motion as applicable to both translatory and rotary motion.

Procedure. All of the subjects were given two tasks to perform on the turntable. Before and after each task was attempted, they were questioned to ascertain their understanding of the relation between the body movements used and successful performance and the physical laws describing this relationship.

Task I. In the first task each subject was given 10 trials in which he was required to turn about in a full circle. The turntable was stationary at the beginning of each trial. Time in seconds and any spontaneous comments of the subject were recorded for all trials.

Task II. In the second task the subject and turntable were made to rotate at 6 rpm and then released in free rotation. The subject had to try to stop the rotation and hold it at a minimum for a 30-sec. trial period. He was not told that it would start moving again if he stopped his arm movements before the 30-sec. period was over. Three trials were given. The number of seconds that the turntable was held stationary and the degrees

*Gymnasts, especially tumblers and trampoline specialists, or divers, would have filled these requirements more adequately but were not available.

of arc it moved during the 30-sec. period were recorded. Thus a perfect trial score would have been 0° rotation for the 30-sec. trial.

After the second task was finished, the subjects were shown a bicycle wheel mounted on a steel bar so that it could be held like an open umbrella.* They were asked if they thought it would have been of any help in the tasks. Those who thought it would were then allowed to demonstrate how they would put it to use on the turntable in each of the two tasks.

The bicycle wheel could be helpful in either task and could be used in any of the following three ways:

(1) It could be used as an extension of the arm to increase the moment of inertia and so get more movement per swing.

(2) It could be held horizontally in front of him and then spun sharply with a thrust of his free hand so that angular momentum would be imparted to the turntable-subject system equal to that imparted to the wheel but opposite in direction.

(3) It could be spun and then turned so that it was in the vertical plane and held at right angles to the body, making bearing contact by pushing against it. This would occur because of the gyroscopic resistance to a change in the plane of rotation.

The detailed procedure for each subject was as follows. The door in the enclosure wall was opened and the subject was read the following instructions:

"See the turntable in the center of the room? Although it is locked now, it can be freed to rotate in either direction. In fact, it rotates so freely that for practical purposes we can consider it frictionless. During the experiment you will be required to perform simple tasks on it while you are standing with your center of gravity over the turntable axis of rotation.

"Your first task is as follows: standing on the center of the turntable while it is free to rotate, you are to make one complete turn without shifting your feet or jumping in any manner. You are not allowed to touch the wall or floor surrounding the turntable. You will start facing the black line on the wall.

"Now you are going to be given 10 trials in which you will have to make a complete turn, returning to the black line. I shall time you on each trial and tell you how you did. I shall say *go* at the beginning of each trial. At the end of each trial you can touch the wall to realign yourself. Use the 2 white patches, the one on the platform and one on the floor, as a guide.†

*This is the type of apparatus commonly used in physics classes to illustrate principles of gyroscopic motion.

†These patches were placed so that the subject was facing the black starting line when they were aligned.

"We should like to have you think aloud whenever you wish. Tell us whatever comes to mind as you try to solve the problem. You can do this either during or after each trial. This is very important! Don't hesitate to tell us whatever you think. Any questions? Try your best, but do not lose your balance or shift your feet in any way."

This statement was followed by this sequence of questions. (1) "Do you understand the task?" (2) "Do you have any idea *how* the problem may be solved?" (3) "Do you have any idea of *why* this technique may work; for example, how to explain why it will work?" (Used only if subject had idea of how he would solve problem.)

The subject was then given 10 trials in Task I. This was followed by these comments. "You got around by ... (a description of the motions used to solve the problem was inserted here). "Do you know how or why it worked for you?"

After about a minute rest, Task II was undertaken. These instructions were read:

"Now you are going to be given a second task. This time you are going to get on and we will start you spinning slowly. When I give the signal (I shall say *stop*), you are to try to stop your body rotation as quickly as you can. ..."

The same series of questions concerning understanding of the problem and its solutions, as used in Task I, was read before and after the trials.

Each subject was given three trials. If the subject started to coast after stopping the turntable, the experimenter exclaimed, "I said *stop*." This was done to keep all subjects working during the full 30-sec. trial. The definition of what "stop" meant was purposely left ambiguous in the initial instructions to allow the subject to figure out for himself whether or not he would continue to coast if he stopped the successful arm motions.

Results and Discussion*

Self-confidence. None of the subjects could remember ever having been presented with a similar problem to solve. In spite of the strangeness of the task, all of the subjects felt that they understood the requirements of the problem. Only three subjects expressed any doubts concerning their

*The 5 per cent level was accepted as statistically significant in all comparisons. Duncan's method (1950) as modified for unequal *N* (1957) was used in all between-group comparisons after the completion of the analysis of variance. Mainland's tables (1948) were used in several cases to determine the exact probability for small sample 2 × 2 contingency tables.

While the oil-bearing turntable was in the process of construction, a preliminary experiment was performed using a mechanical bearing turntable (Cenco) of the type used to demonstrate conservation of momentum in elementary physics courses. The subjects were 19 engineers, 25 liberal arts students, and 4 swimmers. Although the results were not as completely quantifiable as those reported here, they showed the same trends in every detail.

anticipated success. In Task I, an engineer asserted that Newton's third law of motion made it impossible to solve the problem, assuming that the turntable were actually frictionless. In Task II, two liberal arts students and one swimmer admitted that they did not know if they would be able to stop the rotation of the turntable. The rest of the subjects were confident that they could solve the problem.

Performance, Task I. FIGURE 9 presents the time scores for Task I. The poor score of the engineers on the first trial was due to 1 subject who took 117 sec. to make a revolution. If this datum is removed, the group mean dropped to 22.1. This one extreme score was left in for the over-all analysis of variance. As would be expected from the rapid negatively decelerating learning curves, the between-trials effect was highly significant ($P < 0.001$). The between groups and groups × trials interaction did not even approach significance.

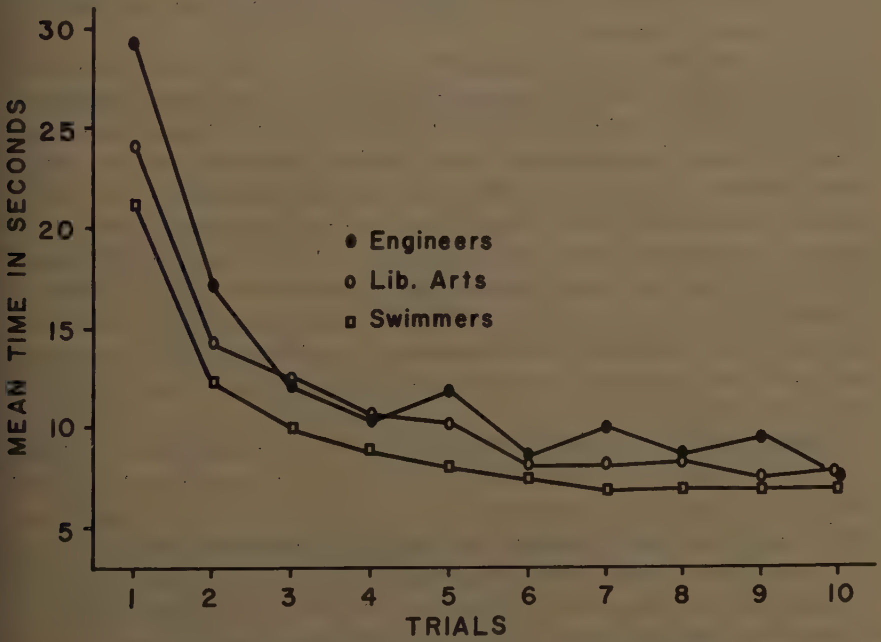

FIGURE 9. Graph showing the time scores on Task I.

Performance, Task II. FIGURE 10 shows the length of time that the subjects were able to hold the turntable stationary during each 30-sec. trial. The groups as a whole improved in performance (between trials, $P < 0.001$) and, although the over-all difference between groups did not reach significance, the group × trial interaction was $P < 0.05$.

The amount of slippage in revolutions per trial is plotted in FIGURE 11. Inspection of FIGURES 10 and 11 show the striking inverse relationship between these independently measured variables. The results of the analysis of variance duplicated that performed on the time per trial held stationary. Again there were no over-all group differences, but the between trials effect ($P < 0.01$) and the group $\times$ trials interaction ($P < 0.05$) were both significant. Postanalytic individual comparisons showed the engineers to be significantly inferior to liberal arts students in time held during trial 3.

Thus although all groups readily learned the task, the engineers did not perform as well on the last two trials. The consistent failure of the engineering students to perform better in Task I or as well as the others in Task II was surprising. In so far as performance was concerned, these students apparently had no positive transfer of their knowledge of physics. This raised the question as to whether this knowledge was used at all. Content analysis of the subject's comments and explanations helped to clarify this point.

Level of understanding of the tasks. Not one of the subjects gave a completely coherent and consistent analysis of the physical principles applicable to the solution of the problem. Although the engineers tended to use somewhat more technical terms in their descriptions, the groups did not differ in the amount of rational insight into the task.

In almost all cases partial insight into the task was either irrelevant or irrational in relation to the actual task. In some cases partial insight tended to produce confusion. Some typical comments are abstracted below.

Electrical engineer (before Task II). "I shall stop it by holding my arms out as far as I can. I don't remember the principle . . . it has something to do with the center of gravity and changing the center of gyration of my body . . . . . ."

Chemical engineer (before Task II). "If I stick my arms out, I shall slow myself down . . . something to do with the center of mass or the center of gravity of the body, but now I don't know . . . I could do it awhile ago (when he was taking physics) . . . I remember the demonstration lecture with a piano stool using weights . . . ."

Mechanical engineer (before Task II). "I can't do anything to remove the inertia of rotation completely . . . by raising my arms I increase my moment of inertia, reducing the velocity . . . ."

Biology major (before Task I). ". . . I should start throwing cigarettes or blowing . . . it will be difficult because you must throw something to make yourself go in the opposite direction . . . for every action there must be a reaction . . . ."

Ibid. (before Task II). ". . . This is impossible because as long as I am in motion, if there is no friction, I'll stay in motion . . . if I can find any

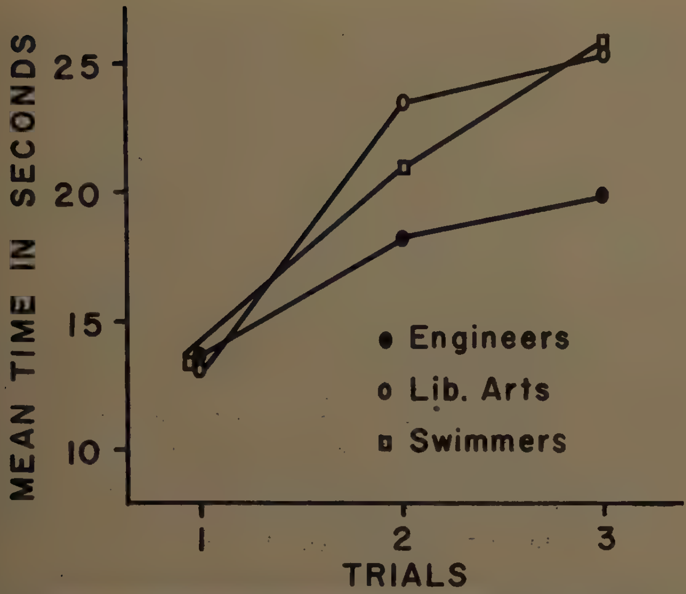

FIGURE 10. Graph showing the time per trial that the turntable was held stationary during Task II.

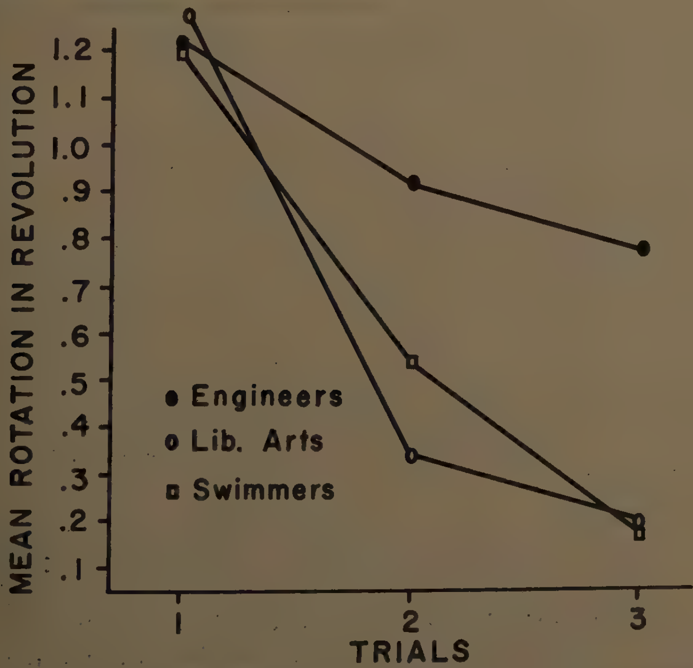

FIGURE 11. Graph showing the amount of rotation in revolutions that occurred after the signal to stop in Task II.

way of stopping, I'll start rotating again, when I quit the method ...."

Civil engineer (before Task I). "... If it is frictionless, nothing will hold me back; therefore, as body moves and my feet are stable, the turntable will move, for the turntable plus the body are one unit."

Mechanical engineer (before Task I). "... I shall have to shift my weight gradually ... you have to screw up Newton gradually for awhile ... the only way to do it is to use air and the residual friction of the wheel.

In general the frequency of even partially correct insights did not increase as the experiment progressed. Successful experience on the turntable (all subjects solved the problem empirically) apparently did not help in the rational analysis of the situation. In some cases the subjects were actually hindered by successful performance! They tended to select irrelevant arm, leg, or body movements as causal factors leading to success. Thus some subjects thought that fanning the air helped, some thought that a fast initial hand sweep followed by a slow return movement was the critical factor, and some thought that crouching on the initial swing and suddenly standing up on the return swing was helpful.

TABLE 1 shows the frequency of subjects that completely missed or misunderstood the applicability of Newton's first and third laws to the problem in assuming that correct movements would make the frictionless turntable coast in Task I and stop dead in Task II. Group differences were not significant in either task. Some examples are listed below.

TABLE 1

FREQUENCY OF ERRORS IN TASK ANALYSIS

Group	Engineers	Lib. Arts	Athletes
Task I, "Coast"	6	11	4
Task II, "Stop"	10	8	3
Expected frequency*	6.3	8.7	5.9

*Computed by assuming constant proportions across groups, corrected for the number of cases in each group.

Sociological major (before Task I). "... Just turn my body and this thing should move me around. If it is frictionless I just need to give it a shove and I shall scoot around ... you don't want me to stop dead on the line, do you? This would be difficult to gauge."

Commerce and finance major (before Task I). "... If I shift the weight once, the momentum of my body would get me started."

Electrical engineer. "... Swinging my arms will develop a torque in

the direction opposite to the motion of my arms and get me started."

Again, it is interesting that the conceptually sophisticated engineers showed as many errors of this type as did the other subjects. Even after finding out that they could not get the turntable to coast in Task I, more than half of them still misunderstood the second task. This failure of subjects to transfer what was learned in Task I to the understanding of Task II was even more surprising since all but one engineer (plus three liberal arts and one swimmer) correctly guessed that Task II was functionally equal to Task I except that the hand motions were reversed in solving the problem. Many even anticipated that it would be more difficult to stop a moving turntable than to start one that is at rest.

Bicycle wheel. As pointed out in the procedure above, the bicycle wheel could be used in three ways: stationary, to add mass and radius to the swinging arm; moving, to obtain a reaction through the act of spinning it; and moving to get bearing contact by working against its gyroscopic stability. Since the engineers were quite familiar with gyroscopic action, this part of the experiment allowed a final test of whether they were at all capable of making constructive use of their knowledge in this situation.

TABLE 2 shows the frequency counts of the responses in this section of the experiment. TABLE 2, A, shows the preliminary predictions. The liberal arts students and the swimmers were not significantly different (Fisher's exact test); thus they were pooled and compared to the engineers (Chi square – 5.67, $p < 0.02$). Thus significantly more engineers thought that the wheel would be useful. TABLE 2, B, shows the use of the bicycle wheel. Although more subjects used the wheel in the spinning condition, group differences were not significant.

TABLE 2, C, summarizes the explanations accompanying the successful use of the wheel. The liberal arts students and swimmers were pooled and the "added-mass" and "spin-to-release" explanations were pooled to get a sensitive test of the engineers' use of gyroscopic principles. The exact probability of group differences in the resulting 2×2 contingency table was found to be 0.0103.

Thus after the completion of both tasks, the engineers finally showed evidence of making use of their technical knowledge in seeing the potential usefulness of the bicycle wheel as a gyroscope.

The fact that the engineers were able to make use of the bicycle wheel as a tool to manipulate the turntable is in sharp contrast with their failure to use their knowledge of physics in the tasks themselves. A unitary explanation of this phenomenon is not possible on the basis of this initial study. However, some possibilities may be noted at this time.

Qualitative observations of the arm movements used in the early trials of Task I showed that almost all of the subjects started successful performances on the basis of "natural" swinging movements of the extended

TABLE 2

FREQUENCY DATA ON THE INTERPRETATION AND USE OF THE BICYCLE WHEEL TO AID PERFORMANCE ON THE TURNTABLE

(A) Preliminary predictions on its usefulness:

Response	Group		
	Engineers	*Lib. Arts*	*Swimmers*
"Will help"	16	14	10
"Can't be used"	0	8	5

(B) Method used:

Method	Group		
	Engineers	*Lib. Arts*	*Swimmers*
Using wheel spinning	12	9	5
Using wheel stationary	2	3	4

(C) Explanation of why method worked:

Use	Group		
	Engineers	*Lib. Arts*	*Swimmers*
As gyroscope	6	2	1
As added mass	2	5	2
Spin to gain reaction	1	8	2

arms, analogous to the passive arm swings used in walking. The striking similarity of these movements between subjects suggests that they may have first occurred passively as an aid in maintaining balance on the turntable. The very low friction of the bearing may have then allowed extremely rapid and efficient psychomotor information to become available in the form of proprioceptive and kinesthetic feedback. The natural tendency to start the swinging movements to maintain balance and the rapid feedback of information as the movements occurred may have combined to make the task an extremely simple one in psychomotor terms, although still a very complex one in abstract physical terms.

Thus the task may not have been sensitive enough to measure possible differences between groups based on their use of physical abstractions.

A second factor in their failure to transfer in the tasks stems from the fact that in our instructions we made no suggestions that the engineers were to attempt to use standard physical principles to explain the tasks.

ı addition, they were not aware of the fact that they were being compared ɔ nonengineers as a group. Thus the instruction and general atmosphere ıay not have produced a set to think in physical terms. This could easily e tested, of course, by repeating the experiment with instructions de-igned to establish a task set to think in terms of abstract physical rinciples (Székely, 1950).

A third factor should be mentioned. The content of the physics courses ı which these abstract principles were developed for the students was uite different from our experimental situation. None of these students ad ever come into contact with the principles of mechanics as applied ı animate biological systems. Thus they may have been victims of functional fixatedness" (Luchins, 1942); that is, they unconsciously ssumed that those abstractions applied *only* to inanimate systems. This ypothesis could also be tested in further experiments. For example, hysical education students could be tested after completing a course in inesiology or physiology, after such procedures as discussions of the echanics of exercise.

A more direct approach to this problem of conceptual transfer would be ı use naive subjects and train them in the specific set of principles ecessary to explain control of body attitude in the no-bearing-contact ituation. This would produce a better controlled and more sensitive easure of the transfer of this training to the problems to be solved on ıe turntable.

In general, it is felt that the consistency of the results in this initial xperiment indicates that this approach may be quite useful in further eneral studies of performance without bearing contact. Subjects could be ested in more complex tasks, in other body positions (for example, clining on back), and with other motor aids (for example, hand or belt r jets). This approach may also be extended to include translatory otions as well as rotation. A "chair" or "bed" mounted on a movable r bearing or riding on packed ball or roller bearings could easily be eveloped for this work.

Summary and Conclusions

A low-friction oil-bearing turntable was developed to investigate the oblem of performance in the absence of bearing contact. Arts students, vimmers, and engineering students were given simple tasks to perform ı this turntable. Observations were made on performance and the level understanding of the tasks. On the basis of the results, the following nclusions may be drawn:

College students rapidly learned to perform equally well in this tuation.

Engineering students were not able to make efficient use of the familiarity with mechanics to aid in the performance or understanding c the tasks.

Engineering students were able to use their knowledge of mechanics t understand the use of a hand-held gyroscope as a tool in these tasks

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